Art. XIV.—*On some Features of the Ordovician Rocks at Daylesford; with a comparison with similar occurrences elsewhere.*

By T. S. HART, M.A., B.C.E.

[Read 12th December, 1901.]

The Ordovician or Lower Silurian Rocks occupy the surface or occur at no great depths over the whole area around Daylesford. Numerous natural and artificial sections show that the rocks are much folded. The general strike is between north and north-west. Mr. F. M. Krausé[1] states that the general strike of the beds in the latitude of Wombat Hill is 16° to 22° west of north, approaching further north more and more to the magnetic meridian. In my own observations several localities further south show a strike much more to the west of north. The dip varies from 45° to vertical. The Ordovician age is indicated by the graptolites found in several localities. Mr. T. S. Hall[2] has correlated a portion of them at least with the lowest parts of the Castlemaine series.

No granitic areas or other extensive plutonic rocks occur anywhere near Daylesford.

The area to the north of Daylesford forms Quarter-sheet 16 N.E., mapped by the late Mr. Norman Taylor, and published 1893; that to the south (16 S.E.) has been mapped by Mr. S. Hunter, published 1895. I propose in this paper to notice certain minor features connected with the folding of the rocks, and to compare them with similar occurrences elsewhere.

An interesting section, presenting unusual features, is seen in the railway cutting at Italian Hill, on the Daylesford-Ballarat Railway, Quarter-sheet 16 S.E., immediately north of the lake (the lake is formed by damming the stream marked Wombat Creek on the map). There is another Italian Hill some miles

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1 Progress Report of the Geological Survey of Victoria, No. 5.

2 Proc. Royal Society of Victoria, vol. vii., New Series.

north-west of Daylesford, which must not be confused with this.

The direction of the railway cutting close to the lake is about N. 25° W., the strike of the rocks N. 40° W., dip south-westerly at 50°. The eastern or inner face of the cutting, about 40 feet high, is thus taken out almost on the bedding planes, or follows them for some distance. The outer low western bank, about 12 feet high, is a cross section of the beds, almost at right angles to the bedding, but the slight angle between the strike and the direction of the cutting allows the same beds to be seen on both sides. The railway turns a little more northerly and produces a deceptive appearance of a twist of the rocks on their strike.

A considerable surface on the inner slope parallel to the beds presents an appearance suggestive of ripple marking. A series of undulating ridges run across it, approximately parallel and nearly horizontally at intervals of 3 or 4 inches. Their upper slope is more steeply inclined to the general direction of the surface than their lower, and they are crossed obliquely, especially on their downward slope, by smaller ridges, also roughly parallel to one another and undulating. The rock is a micaceous sandstone.

Shallow curved depressions also appear, and a little further on the exposed surface of a hard sandstone is crowded with peculiar pits or pockets. These are hollows of various shapes and sizes, one, about 2 feet 6 inches across, reached a foot below the general surface of the bed. They are bounded by curved surfaces, and are generally steeper on one side, meeting the gently undulating surface of the bed, or of another pocket at a considerable angle. Often a number of the pockets are confluent. The sides of the pockets are frequently marked by curved ridges parallel to one edge and ending abruptly with the surface on which they appear. The pockets are usually empty, but sometimes filled by a softer sandstone, or by cleaved and jointed slate. Pockets filled with slate at one place form a prominent line running obliquely up the side of the cutting in a position which would correspond to the outcrop of a thin bed of slate, but the slate is discontinuous. On the opposite side of the cutting a disconnected slate patch is noticeable in about a corresponding position. The largest slate patch exposed on the east slope measured 16 inches by 12 inches, on the other side one was noticed in cross section measuring

22 by 9, the long direction roughly parallel to the beds. On the western slope also patches of softer sandstone can be detected in the sandstone. They are comparable in shape and position with the pockets, and their upper surface, sometimes at least, is also curved though not so strongly as their lower. Slate in the pockets in the sandstone is not, however, confined to the one band, others also occur, and it is probable that more of the pockets were once occupied by slate. It is said that when first exposed the sandstone in the pockets was hard. The hard sandstone in which the pockets occur softens near the surface and presents an appearance very like that in the pockets.

On the western side the chief point of interest is the form of the softer beds intervening between the sandstones. Sandstones greatly predominate at the south end of the cutting, and at first the slate beds vary slightly in thickness from point to point, the boundaries of the beds undulating and the upper and lower surfaces of the slates not corresponding. Further on, a thicker bed of slate occurs, which is very much contorted internally. At first the laminae of the upper portion are contorted and overfolded, further on a fracture crosses the bed obliquely, accompanied by a number of minor parallel fractures, all of which, as regards the laminae, present the appearance of thrust planes, but the contacts with the adjacent sandstones above and below are only deeply curved and not faulted. The result of this is a considerable thickening of the slate at this part.

In another slate bed a long wedge of sandstone is seen to project into the slate. This wedge measures about 8 feet in length on the exposed surface.

Further north there occur slate beds of very irregular character. One isolated patch of slate is of very irregular form, but with its longest diameter parallel to the beds, and a crack with slate fragments, continues in the same direction. Below it is a band of much broken slate mixed with coarse sandstone and of very irregular thickness. This continues north and takes the form of fairly continuous slate beds, with coarse sandstone between. An oblique hollow occurs in the underlying sandstone, into which a mixture of slate and course sandstone enters. The lower slate band subsequently divides, a small portion continues on its natural course for a short distance, but a more prominent oblique band of slate crosses the sandstone, about 3 feet thick, almost to the slate bed below. The sandstones above and below this band differ somewhat in texture, and numerous apparently detached slate fragments occur below the slanting band. Following this, the sandstone is largely cut away by local faults, and a hollow formed, which is filled by a confused mass of slate and sandstone fragments, the bed above also entering the hollow and being highly contorted, this contortion extending beyond the limits of the hollow. Beyond this the sandstone seems to resume a texture similar to that before the slanting band of slate. In the southern end of the band, and the mixture which enters the hollow in the sandstone below, the appearance presented is that of a conglomerate of slate fragments in sandstone, though many of the apparently isolated fragments of slate are no doubt really united.

A number of slate fragments enclosed in sandstone can be seen in the next cutting towards Daylesford, somewhat angular in outline and up to 9 by $2\frac{1}{2}$ inches in size.

At first sight the explanation might be suggested that the whole of the results might be due to deposition of somewhat plastic clay lumps with the coarse sand, accompanied by contemporaneous erosion of the underlying beds. A more detailed examination at once shows this to be untenable. One of the most conglomeratic patches is in the hollow of the sandstone below, which could not have remained open unsupported. It also fails to explain the gradual change to parallel bands of slate and sandstone. The alternative is that this is a pseudo-conglomerate, formed by breaking up of once continuous beds, and subsequent examination revealed all that was necessary to support this view.

Unequal thickening and thinning of slate beds between sandstones may be noticed in almost any railway cutting in the Ordovician rocks in this district. Slate beds are seen to be often completely interrupted on the exposed face. The variation in thickness and interruption is often connected with the jointing and other cracks in the neighbouring sandstone, and occasionally with small local faults. Sometimes the slate gradually thickens and abruptly stops at a joint or fracture in the sandstone. Contortion of the laminae is noticed in some of these cases.

The squeezing out of the slate goes so far as sometimes to show only occasional slate patches along a definite line of junction of two other beds. The connection with joints and fractures and contortion sometimes noticed, as well as the irregularity of the occurrence, indicates this as squeezing out, not thinning out.

The tendency of more plastic beds to thicken in the curves of a highly folded series and to squeeze out from the flanks of the folds is well known. If we look at the ordinary folds of the Ordovician rocks here we will find that a large portion of any bed is approximately a plane between the more sharply curved portions. If we have then a plastic bed whose thickness is comparable with the minor irregularities and small displacements of the more rigid beds alongside, it will be completely squeezed out irregularly, and patches will be left which have no passage by which they can move towards the folds, so that, in the extreme case we should expect a slate bed not to be completely squeezed into the folds, but to be represented by a number of more or less isolated remnants.

Even if no considerable area of the beds was near a plane, the boundary of the area from which the slate was removed would be irregular, and a section passing anywhere near this boundary would show more or less discontinuity in the slate.

The squeezing out would not necessarily take place especially at the places where the strata were most steeply inclined.

Again, the material of the more plastic beds is frequently seen to enter cracks in the adjoining sandstone, and this is most common when the cracks make an angle with the bedding considerably less than a right angle. By the gradual widening of this crack, either by bending of the bed or by the pressure forcing the more plastic material into it, we thus obtain a wedge of slate in a sandstone, and a corresponding wedge of sandstone in the slate. If such a wedge is cut transversely it may appear as an isolated fragment of slate in sandstone near to the main slate bed; but it may also appear as an isolated sandstone fragment included in slate. Examples of this are seen in various sizes up to that instance at Italian Hill. In an extreme case a considerable portion of a slate bed may appear as isolated fragments. As the irregular folding and yielding of the beds must result in frequent readjustments of the strains, it may often happen that a crack which once tended to open again tends to close, and a slate fragment may be thus pinched off from the bed. Numerous cases were noticed of slate fragments isolated in sandstone, but with a crack running to a neighbouring slate bed, and to the place where such a bed might have been. Some of these may not unlikely be wedges, but some really isolated.

This method of mixing of slate and sandstone may take place wherever the cracking of the sandstone occurs, and the slate is under pressure tending to squeeze it out. It may easily occur at anticlines even, if only the packing of slate is sufficiently complete. Its final stages may appear completely conglomeratic in section.

These depend essentially on the fact that one material is more plastic than the other, and are likely to be more marked the greater the difference ; hence the occurrence of the most conglomeratic appearance with the coarsest sandstone. But in a case like that at Italian Hill, when a slate is associated with a thin coarse sandstone, and all is between thicker sandstones, the mixed series will retain some plasticity even after the breaking up has begun, as long as slate is fairly continuous, hence the squeezing of the mass into the crack in the underlying sandstone. Its squeezing out between the sandstones at its south end may also be partly due to this.

In a mixed slate and sandstone series between thicker sandstones, the sandstones may be cracked across, and the slate squeezing into the cracks become continuous right across the sandstone. This may be seen both at Leveret's cutting (107 to 107½ miles), and at the big Wombat cutting (101½ to 102 miles) Ballarat-Daylesford Railway.

The direction of the longer axis of slate fragments in the sandstone is variable, the cracks which contribute to their formation may or may not belong to some regular series of divisional planes.

At Bald Hills Creek near the locality of Note 12, on Quarter-sheet 16 N.E., occur slates with interlaminated hard sandy beds to quarter-inch thick. These can be seen as regular parallel beds, then becoming variable in thickness, then as nearly or quite disconnected lenticular patches, and at places the thin beds are bent into sharp folds, and the sandy beds are often interrupted, portions of them appearing as isolated fragments on a slaty base. But in a series in which sandstone predominates such effects traceable to contortion were not distinctly noticed.

A band of slate patches and strings passing into a continuous band of slate occurs near the above at Bald Hills Creek. The slate fragments being mostly angular this might be called a breccia, but as such isolated slate fragments more usually are to some degree rounded, and in extreme cases appear well rounded at all edges, the term pseudo-conglomerate seems preferable for the more marked development at Italian Hill, and in some instances mentioned below.

The surfaces of slate fragments enclosed in sandstone have often a satiny lustre, probably due to development of a film of sericite. This may be helped by sliding at the contact during or subsequent to the isolation of the fragment.

Conglomerates have been recorded elsewhere in the Ordovician rocks of Victoria, some of which are analogous to that at Italian Hill.

At Bendigo, Mr. E. J. Dunn[1] records the occurrence of a conglomerate "in several mines and at different horizons" of "rounded often flattish fragments of black slate, very soft, and the spaces between are filled with coarse-grained sandstone." His explanation is that the shaly material appears to have been deposited, torn up while scarcely firmer than clay and redeposited almost in situ with coarse sand. I visited the typical locality of the conglomerate at the Golden Pyke Mine It occurs close to and at an anticline. The slates are much contorted internally and contortion is also visible in some slate fragments in the conglomerate. Irregular thickening and thinning of the slates occurs, and they are frequently squeezed into cracks in the adjoining sandstones. The conglomerate is not always clearly marked off from the adjoining sandstone. The general arrangement of the slate is parallel to the bedding; both the sandstone and slate are sometimes continuous for some little distance. Sandstones greatly predominate in this part of the mine.

Near Chewton, Mr. T. S. Hall[2] describes a similar conglom-

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1 Report, No. 1, on the Bendigo Goldfield, 1892.

2 Proc. Royal Society of Victoria, vol. vii., New Series.

erate occurring in three localities. One locality is a little to the Melbourne side of the 73 mile post. The sandstone here in which slate fragments appear embedded is of coarser texture than others in the vicinity, though fine compared with what might be expected in a conglomerate with fragments of the size seen. Near the 72 mile post slate bands and fragments are again seen in coarse sandstone, the general direction of the slate being parallel to the beds, and their arrangement might at one place be due to contortion. Through the cuttings from Chewton to the Elphinstone tunnel irregular thickening of slate, sometimes at joints and cross fractures in the sandstone, interruption of slate beds and squeezing of slate into cracks were frequently noticed, and apparently detached slate fragments. At one place beds of sandstone up to 11 inches in thickness are broken and the intervening slates come together.

A conglomerate of somewhat different character occurs under the down distant signal post at Chewton. The exposed surface shows subangular and rounded sandstone fragments in a slaty paste, the slate between the sandstone sometimes shows contortion; slaty material also enters the cracks in the sandstone, the thickest sandstone bar runs for about four feet with a varying thickness to three inches, but most of the sandstone appears fragmentary. This occurrence might represent the extreme stage of contortion such as that at Bald Hills Creek, but at Chewton the sandstone is in greater proportion and contortion not so clear. It approaches closely to the other conglomerates, except that the slate predominates and appears therefore as the more continuous matrix, the sandstone appearing fragmentary.

The catalogue of the rocks of Victoria in the Technological Museum records a conglomerate of fine grained, often micaceous sandstone, enclosing rounded pieces of slate from Section 50, parish of Spring Plains, Quarter-sheet 13 N.E. I find no note of this on the Quarter-sheet, but oblique lamination of slates and sandstone (to be referred to later) and contortion are frequently recorded near this point and elsewhere on this sheet.

On Chinaman's Creek, north-west of Castlemaine, Quarter-sheet 14 S.E., a note records fragments of slate embedded in a surface of sandstone.

In the railway cuttings south of Creswick were noticed isolated slate patches, probably due to both causes of squeezing out and pinching off. Wedges of slate projecting into sandstone were also noticed.

Quartz was noticed associated with these conglomerates at the Golden Pyke Mine and near Elphinstone tunnel, but not affected by the breaking up. It is clearly of subsequent date.

Conglomerates are also recorded in the Ordovician Rocks at several patches near Lauriston, where the note probably refers to some overlying rock, the areas being outlined, but not coloured differently to the Ordovician.

At Coimaidai there is a true conglomerate of small extent described by Messrs. Officer and Hogg.[1]

On the Keilor Plains, Quarter-sheet 7 S.E., several bands of conglomerate are noticed. These are true conglomerate, but their Ordovician age is not certain.

An analogous mixing of beds of different character is noticed by Professor David and Mr. Pittman near Tamworth, N.S.W. "Though as a rule the tuff beds are regularly and evenly interbedded with the radiolarian clay shales, instances are not infrequent where these rocks are confusedly intermingled together." A reproduction of a photograph shows disturbed masses of radiolarian shale enclosed and entangled in a thick bed of submarine tuff. The two views figured are described as "laminated and contorted Radiolarian chert in submarine acidic Tuff" and "Radiolarian chert with submarine Tuff crushed into them."[2]

Mr. Pittman describes certain conglomeratic rocks at Lyndhurst[3] in which the included fragments of claystone are exceedingly angular, and appear to be the remains of claystone which have been intruded and broken up by the tuffaceous matrix through which they are now scattered. The disturbance is ascribed to injection of steam and other gases.

The breccia from Maldon, in the Technological Museum, is clearly due to brecciation of a rock subsequent to its formation.

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1 Proc. Royal Society Victoria, vol. x., New Series.
2 Q.J.G.S., lv., 1899.
3 Records G.S. N.S.W., vol. vii.

An appearance of ripple marks has been before noticed as occurring at Italian Hill. Ripple marking is also seen at Bald Hills Creek in the sandstone, and at Jim Crow Creek, below Spring Creek, in a series of slates in which faulting parallel to the beds has occurred on three different beds.

"Ripple marks" have been frequently noticed in the Ordovician Rocks of Victoria.

I find only one mention of ripple marks on the Quarter-sheets, near Metcalfe (13 S.E.) "nearly vertical contorted mudstone and shales, some of the beds are ripple marked." Oblique lamination and cross-grained sandstone (to be referred to below) are also noticed near here.

Ripple marks are described by Mr. Dunn as common at Bendigo at many localities, and horizons, and regarded as true ripple marks.[1]

Mr. T. S. Hall, however, referring to similar occurrences at Castlemaine, suggests that there and at Bendigo they are the result of crumpling during folding.

Mr. C. C. Brittlebank[2] says of the rocks at the Werribee Gorge, "contortion and pseudo-ripple markings are well developed, the latter appear more extensively in localities which have been subjected to the greatest strain and pressure."

Mr. G. W. Lamplugh, writing of crush conglomerates in the Isle of Man, says:—"Where packing has taken place, the lines of stratification are confused in a series of wrinkles, which emerge on the bedding planes, as small parallel folds closely resembling ripple marks;" to these he applies the term pseudo-ripple marking.[3]

Mr. E. R. Faribault, of the Geological Survey of Canada, describing saddle reefs in Nova Scotia, where, however, the folding has not proceeded nearly so far as at Bendigo, states, "the corrugations and crumplings are more pronounced in the slate and quartz, and owe their origin to the sliding of thick beds of quartzite over one another, between which the softer bands curve and buckle in a wonderful manner."[4]

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1 Report on Bendigo Goldfield, No. ii., 1896.

2 Vic. Naturalist, vol. xviii.

3 Q.J.G.S., li.

4 Austr. Mining Standard, Oct. 29, 1899.

We may notice also that in the Daylesford cuttings joints occasionally show a somewhat wavy surface in sandstone (in slate they are much smoother) and that there is a slight rippling of the surface of the pockets at Italian Hill.

A consideration of the effect of the crumpling on the junction of two dissimilar rocks will lead to the conclusion that it is highly improbable that such a surface, if originally even, should remain so at any place when packing has taken place in one of the rocks, and the inequalities would be likely to assume some linear arrangement, as the folds within the crumpled bed do. The fact that the main ridges of the apparent ripple marks at Italian Hill are nearly parallel to the strike agrees with this.

At Daylesford, Bendigo and Chewton, and probably at most other places, in the Ordovician rocks in Victoria the evidence of movements and packing in the slates is so definite and widespread that the existence of apparent ripple marking has an adequate explanation in this, and is, at least, no evidence of original ripple marking.

The pockets in the sandstone at Italian Hill do not appear to be a common feature. They can be seen also in the by-wash of the Lake, where some might at first sight be mistaken for potholes, but their form is easily recognised and they are revealed by slight slipping in the solid bank. They are probably in the same beds as appear in the cutting. They are also seen at the north end of Leveret's cutting and at the Breakneck, north of Hepburn, and possibly at Chewton.

It is possible for sand to be deposited with an extremely uneven surface in rough water (as I noticed in sludge from sluicing deposited among rocks in Jim Crow Creek), but here there is no evidence of such currents and the edges of the pockets are too definite. The band of slate fragments filling some of them suggests that they are the hollows which have once been occupied by the fragmentary remnants of a squeezed-out slate bed, but others contain sandstone and are not on any evident line of a slate bed. If, however, a slate bed were to be squeezed into isolated patches the neighbouring sandstones being at places in contact this would tend to the production of very irregularly distributed strains in the sandstone, and hence might set up irregular curved fractures and irregular consolidation producing different weathering. The surfaces of the pockets do not differ from the sandstone any more than is common in joint surfaces and other fractures in such sandstone. At Leveret's cutting in one pocket a banded arrangement of strings of quartz and limonite was noticed, but here the whole rock was irregularly traversed by such strings, and at the typical instance at Italian Hill no concretionary action was noticed.

The sandstone beds at many localities contain a series of more or less undulating and usually discontinuous thin bands of fine grained material containing mica. Sometimes these are nearly parallel to the stratification, sometimes nearly parallel to the cleavage or to joints. In the large railway cutting near Wombat, a stepped junction with the neighbouring slate bed is noticed, as if a slight slipping had taken place on these planes. Near here it is possible to get clear observations of dip of strata, cleavage, these micaceous bands, and three sets of joints. These bands here agree most nearly in direction with one set of joints.

At Bald Hills Creek they are well developed, and form the "oblique stratification" mentioned in the note to the Quarter-sheet. The junction with the neighbouring argillaceous beds on both sides is somewhat indefinite, and the sandstone between them turns and forms lenticular patches in these beds nearly parallel to their general direction. They are parallel in several sandstone beds, but afterwards change their direction. Mr. N. Taylor's sketch shows the actual point at which the change takes place, which, however, I did not see. That they are not really stratification is clearly seen by their relation to the next beds, and their great regularity of development would also be against current bedding.

South of Creswick in a railway cutting they are well developed, standing out somewhat in the friable sandstone (probably owing to the mica flakes giving them some firmness, though soft). Here they may be seen to curve considerably and become less definite on approaching the slate beds from one side, but on the other side they continue unaltered to the slate. Their direction is near that of the cleavage.

Mr. E. J. Dunn notices a similar structure at Bendigo under the name of "fissuring," and regards it as a coarse development of cleavage.[1] He ascribes the finer material to the rubbing together under great pressure of the opposite faces of the "fissure," and the difference of direction from the cleavage he regards as "probably the result of torsion in the sandstone." A radial arrangement around the anticlines and synclines is noticed, and the fact that movement has taken place on these lines is seen by the notched boundary with the slate. One side of such notches I noticed to be often parallel to the "fissuring." But at the Golden Pyke Mine, where it and the cleavage are well developed, I noticed no corresponding change of cleavage direction with the change of direction of the "fissuring" round the anticline.

An exactly similar arrangement is well marked at Chewton, with the same notched boundary of the slate. It is described by Mr. T. S. Hall as jointing. I noticed it well developed at two synclines between Chewton and the tunnel. Its strike is about the direction of the syncline, and it is not affected in its radial arrangement by the fact that the axial plane of one of these synclines is considerably inclined.

At another place in these cuttings similar lines were seen in a direction more nearly horizontal than vertical.

The same structure is probably referred to by the term "oblique lamination," used by Mr. Norman Taylor in Quarter-sheets 13 N.E. and S.E. I do not find it noticed on the other Quarter-sheets. These surfaces, then, appear to have no constant relation either to the cleavage or jointing. The finer material on them might result from crushing or from grinding, the arrangement of the mica flakes being in the one case at right angles to the pressure and in the other parallel to the motion. But their discontinuity in most cases and their curved form, sometimes pronounced, agree best with crushing under pressure. Their regular arrangement at the anticlines and synclines, and their variable development, both in direction and degree of definiteness and continuity, seem more likely to be connected with the distribution of the strain within the individual beds than with the forces acting on the mass as a whole. If the strata were being folded under the pressure of superincumbent

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[1] Report on Bendigo Gold Fields, No. II.

strata, both anticline and syncline might crush under their load as arches, and produce radial surfaces of crushing, unless the packing of the argillaceous beds were sufficiently rapid to prevent it.

In the straighter portions of the folds the direction of the pressure might approximate to that of the general pressure; that is, these surfaces might approach the cleavage direction, or it might tend to be at right angles to the beds, in which case these surfaces would approach the direction of stratification.

The fact of actual movement on these surfaces in many cases would then be the the result of yielding by slight slipping on planes of weakness already established. Their curving to the slate beds, as at Creswick, would probably be due to a yielding by a viscous shear along these more plastic beds. At Bald Hills Creek both of these have very likely taken place, and this may contribute to the abnormal strike 13° east of north, though further north, at a short distance, where this structure had disappeared, a normal strike N. 11° W. had been resumed.

The series of phenomena described all seem to indicate that in examining the effects of folding on a mixed series of rocks of different character due attention must be given to the differences of rigidity and probably compressibility of the different beds, and their manner of yielding under the strains to which they have been subjected.